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SERVICES FOR SCIENCE AND EDUCATION

Efficacy, Safety, and Ergonomics of the EMS Swiss Lithoclast® Trilogy in Percutaneous Nephrolithotomy: A Review

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ABSTRACT

Purpose: The Swiss Lithoclast Trilogy® is a novel percutaneous nephrolithotomy (PCNL) technology used for kidney stone fragmentation. It has a trifecta effect, including mechanical fragmentation, ultrasound lithotripsy, and suction to remove stone fragments. Some comparative studies have reported a higher stone-free rate, increased safety and lower operative time, yet robust evidence remains inconclusive. We reviewed studies investigating clinical safety, efficacy, and ergonomics of PCNL for treating renal stones. Methods: We reviewed 11 studies investigating Swiss Lithoclast® Trilogy for PCNL from 2017 until September 2024. eywords were used to search PubMed, Google Scholar, Scopus and Web of Science databases for relevant studies. After applying eligibility criteria and excluding animal and laboratory studies, 11 studies were included in this systematic review. Data was extracted for efficacy, safety, and ergonomics and analyzed to synthesize the results. Results: Out of 11, 2 were retrospective cohorts and 09 were prospective studies. The Swiss Lithoclast® Trilogy exhibited higher efficacy in stone fragmentation and clearance than traditional techniques. For mini PCNL, the stone fragmentation rate was reported up to 15.75 ± 20.81 mm^3/sec. For supine PCNL, the

stone fragmentation rate was 20.33 +/- 27.83mm³/sec. Lastly, Swiss Lithoclast® Trilogy was associated with high ergonomic satisfaction, and no significant complications. Conclusions: EMS Swiss Lithoclast Trilogy® for PCNL exhibits efficacy and safety with variable ergonomics. However, limited data are available and further prospective and randomized trials comparing EMS Swiss Lithoclast® Trilogy with equivalent technologies for PCNL are warranted to determine its role relating to the stone type and procedure.

Keywords: Kidney stone, Percutaneous nephrolithotomy, mini percutaneous nephrolithotomy, EMS Swiss Lithoclast Trilogy®.

INTRODUCTION

Renal stones are a common urological problem with an increasing incidence globally [1]. Management ranges from conservative to surgical intervention. Percutaneous nephrolithotomy (PCNL), first described in 1976, is a form of surgical treatment where a small tunnel of a few mm is created into the kidney from the skin [2] and is the preferred treatment for renal stones > 20 mm in diameter [3].

The first step in PCNL is the pelvicalyceal system (PCS) puncture with a special needle under ultrasonic or fluoroscopic guidance. Next, a guidewire is passed through the needle, which helps in the dilatation of this tract from the skin to the pelvicalyceal system. For standard PCNL, the Tract is dilated up to 26-30 French Unit (FR), 14-21 FR for mini PCNL, and 11 to 13 FR in case of ultra-mini PCNL. Following dilatation, an Amplatz sheath is placed in the dilated tract between the pelvicalyceal system and outside through the skin. A nephroscope is then passed through this sheath to visualize the stone in the kidney, permitting either fragmentation into small pieces or dusting.

The stone fragmentation is typically performed with laser or non-laser lithotripters. Pneumatic Lithoclast, ultrasound Lithoclast, and Electrohydraulic are examples of non-laser lithotripters [4-6] Laser is a newer modality energy source used to fragment and dust renal calculi [7]. However, each energy source has a different stone clearance, stone-free rate (SFR), total operation time, potential for blood loss, complication rate, and the length of hospital stay [8,9].

Pneumatic Lithoclast is the older method of stone fragmentation and utilizes a hammer jack phenomenon to break the stone into small pieces with subsequent removal via a nephroscope. Although a powerful energy source suitable for hard stone, it is associated with stone retropulsion and inadvertent injury to the pelvicalyceal system, and a laborious technique [10].

Ultrasonic stone disintegration is more suitable for soft stones [11,12]. Holmium Laser in PCNL permits good stone clearance and facilitates shorter hospital stays with less fluctuation in hemoglobin level [13,14]. Thulium fiber laser (TFL) is an effective modality with less retropulsion [15]. EMS (Electro Medical Systems) Swiss Lithoclast®Trilogy is a combination of ultrasound, electromagnetic impactor, and a suction device system for stone fragments [16]. The Olympus CyberWand Twin Ultrasonic Lithotripter and Shock-pulse-SE™ (Olympus, Tokyo, Japan) are other dual-energy intracorporeal energy systems [17].

The most recent innovation in intracorporeal lithotripsy is the Swiss Lithoclast® Trilogy (EMS, Nyon, Switzerland) or Trilogy [18]. It uses suction devices to collect the stone particles in a tube, which is then broken using an electromagnetic energy from a single probe, and is converted into fine particles with ultrasound energy. Trilogy permits effective stone clearance in a shorter time frame [19,20]. Trilogy has been tested in bench studies with good efficiency [21]. Clinical studies have been performed worldwide with variable outcomes [19]. However, a comprehensive summary of these studies in terms of their efficacy, safety, and ergonomics remains elusive. We aimed to bridge this gap in the literature by critically examining the published data regarding EMS Swiss LithoClast® Trilogy for PCNL in terms of ergonomics, safety, and efficiency.

MATERIALS AND METHODS

All studies were identified by using Mesh word subheadings in PubMed. No additional articles were identified on the Web of Science. A Random search of PCNL and Trilogy was also performed on Google Scholar. The initial search words were grouped into two categories, including, lithotripters and PCNL.
A revised Search strategy was then applied using the criteria listed.

1. Trilogy or EMS Trilogy, EMS Trilogy lithotripter, EMS LithoClast® Trilogy Lithoclast, Lithotrite, lithotripter or dual-energy lithotripter*
2. PCNL, PNL, MPCNL, Mini PCNL, Mini PNL, mini percutaneous nephrolithotomy, Percutaneous Nephrolithotomy, or endourology.
3. 1 and 2
4. Studies limited to the duration between 2017-2024

Using these criteria, a total of 93 articles were retrieved from Pubmed and Google Scholar. Among them, 25 full-text articles were selected after excluding studies where Trilogy technology was not used for PCNL. All articles were then screened by using the SQR3 (Survey, Question, Read, Recite, and Review) technique. A total of 11 studies were filtered after applying the stringent inclusion and exclusion criteria. Critical Appraisal Skills Program (CASP) checklists were used for critical appraisal. The outcomes were documented in tables. Inclusion criteria encompassed studies from January 2017 to September2024, featuring EMS Trilogy in PCNL exclusively. Studies in pediatric populations, abstracts only, laboratory settings, or animal models were excluded. Studies that did not report Trilogy PCNL in bilateral kidneys as two cases were also excluded. Inclusion criteria were the comparisons of EMS Trilogy with other PCNL technologies. Data from the 11 selected studies was extracted to develop an excel sheet. Further tables were developed from that data based on stone characteristics, specific procedures, and Surgical experience. Findings were further described as a summary. A detailed discussion for horizontal alignment was developed with references using Mendeley software [22].

We used the following operative definitions in this manuscript.

- **Efficacy:** means stone clearance/stone-fragmentation rate and stone-free rate.
- **Safety:** means the number of complications and type of complications.
- **Ergonomics:** means operator comfort during PCNL using Trilogy recorded on a Likert scale of 1-10, where 10 is best, and 1 is poor.

- **Drop in hemoglobin:** Drop in hemoglobin level post-operatively compared to preoperative level.
- **Post-operative complications:** Any change in the recovery of the patient or complication as per Clavien Dindo classification for surgical complications.
- **Surgical time/operating time:** time from the start of procedure sign-in until sign-out.
- **Need for auxiliary procedures:** need for further modality of treatment (not PCNL) for any residual stone.

RESULTS

As summarized in Table I, out of 11 studies, 9 were prospective and 2 were retrospective. Five comparative studies examined the Trilogy, laser (Ho: YAG, Thulium), and Shockpulse-SE lithotripters. Of these five studies, three found that the Trilogy lithotripter was more efficient at stone fragmentation than the others [9,24,25]. One study reported equal efficiency between Trilogy and high-power lasers [38], while another found Trilogy to be less efficient than both laser and pneumatic lithotripters [40]. The remaining six descriptive studies characterized the Trilogy lithotripter as a safe and effective device. The system was frequently praised for its safety, with low rates of infections or complications such as fever, urosepsis, and bleeding, as shown in Table II. Table III highlights that several studies emphasized the ease of use and surgeon comfort with Trilogy, particularly in terms of ergonomics and handling.

The findings from the eleven selected studies are reported in tabular form.

Table I: Types and the basic characteristics of the selected studies. (TFL; Thulium fiber laser, PCNL; Percutaneous nephrolithotomy)

Author and Year	Type of Study	Aims	Number of patients	Mean Stone diameter (mm)	Stone density (HU)	Stone volume (mm3)
Patil, A. et al ,2021[9]	Prospective comparative study	The efficiency of Trilogy™ and TFL in (mini-PCNL).	Total n=60 n=30 Trilogy n=30 TFL	27.60 ± 10.17 mm	1172.9 ± 313.5HU	3718.9 ± 3038.7mm³ (3D-DOCTOR™; Able Software Corp., Lexington, MA, USA).
Sabnis et al, 2019[16]	prospective clinical trial	study safety and clinical efficacy of Trilogy in patients	Total 31 n=20 sPCNL n=11 mPCNL	24.1 ± 12.5	1229 ± 206 vs. 1168 ± 344 HU (miniPCNL vs. SPNL)	Mini PCNL (3776.1 ± 2132 mm³) sPCNL (7096 ± 6441mm³) 3D-DOCTOR™; Able Software Corp., Lexington, MA, USA).
Thakare, N., et al ,2021[20]	prospective non-randomized study	efficacy and safety of the Swiss LithoClast® Trilogy	Total 157 n=133 sPCNL(>22Fr) n=24 mPCNL (<20Fr)	24.5 mm (range 8–70 mm),	858.22 HU	7117.63 (± 9581.5) mm³ By formula 4/3 × { × (a/2) × (b/2) × (c/2)
Gao, M., et al 2022[23]	retrospective cohort with the matched control group from 2018-2021	perioperative enhanced recovery after surgery (ERAS) protocol for patients with PCNL and Trilogy and control group with traditional protocol	Total 104 sPCNL Cohort	44.3mm SD (21.5)	1088HU SD (681)	X
Timm, B., et al 2020[24]	Retrospective cohorts	evaluation of the efficacy of the 1.5 mm Swiss Lithoclast® Trilogy (Trilogy) rigid probe	Total 60 n=30 mPCNL n=30 Holmium laser	26.7mm	1,193.4± 28.3(HU)	5936.5 ± 2814.1 Calculated From 3-axis dimensions on CT

		and compared the results to cases performed with a 30 W Holmium:YAG (Ho:YAG) laser				
Large, T., et al 2021[25]	prospective multi-institutional randomized trial	comparing outcomes of PCNL using two novel lithotripters, Trilogy vs Shockpulse-SE lithotriptor	Total 100 Trilogy (n = 51) ShockPulse-SE (n =49).	23.2 +/-13.1	927 +/− 386.1HU	4.18 – 4.79 cm^3 quantitative Stone Analysis Software (qSAS) developed by the CT Clinical Innovation Center (Rochester, MN, USA
Nottingham, C.U., et al 2020[19]	prospective multi-institutional trial	critically evaluate the initial experience with the Swiss LithoClast® Trilogy lithotrite during percutaneous nephrolithotomy (PCNL).	43patient (50 PCNL) 7 were bilateral PCNL	22 (12)	780 (362)	X
Ejaz, M. et al 2023[40]	Prospective comparartieve study, single center	To compare outcomes of combined electromagnetic with ultrasonic lithotripter, pneumatic ballistic lithotripter, and holmium laser lithotripter among patients at a Tertiary Care Hospital.	A 30 B 30 C 30 n=90	10-20 mm A 9(30) B 16(53.3) C 12(40) 20-30 mm A 11(36.7) B 14(46.7) C 6 (20) 30-40 mm A 6(20) B 0 C 5(16.7) >40 mm A 4(13.3) B 0 C7(23.3)	X	X
Cauni VM, et al 2023[26]	prospective, randomized study	Assessment of safety and effectiveness	59	35.6 mm	710.1 ± 235.5	419.8 ± 263 mm^2 Surface area (not volume)
Kindler et al 2024[41]	prospective non-randomized study	To evaluate the treatment efficiency of 1.9mm Trilogy probe	110	25mm	x	x
Manzo et al 2024[38]	prospective non-randomized study	To study the most effective method in kidney stones fragmention among Ho:YAG & Lithoclast Trilogy EMS	83, laser grp n=40, Trilog n=43	laser - 20.1+/-5.8mm Trilogy -20.8+/-7.6 mm	x	laser -1602(915-2766) mm^3 Trilogy - 1488(703-2735) mm^3

Table II: The characteristics of the surgical procedures performed in the eleven selected studies. (PCNL -Percutaneous lithotripsy, TFL- Thulium fiber laser, UTI – Urinary tract infection, s-PCNL – Supine PCNL, BT- blood transfusion)

Author and Year	PCNL tract	Probe	Position	Stone fragmentation rate	Procedure time	Stone clearance	Hemoglobin (Hb) drop/Blood transfusion(bt)	Infections
Patil, A. et al ,2021	mini-PCNL (18 FR)	1.9mm Trilogy 60-W SuperPulse TFL 400 µm	Prone	5.98 ± 4.25mm^3/sec Trilogy 3.95 ± 1.00mm^3/sec for TFL (p = 0.015)	32.48 ± 15.39 min Trilogy™ (Puncture to stone clearance) 28.63 ± 18.56 min	Trilogy 96.6% at 48 Hours 100% at one month TFL 76.6% at 48 hours	1.19 ± 0.76gm/dl BT- 0 0.99 ± 0.74 g/dl BT- 0	3 UTI antibiotics 2 UTI

					TFL (p = 0.38).	100% at one month		
Sabnis et al, 2019	miniPCNL (15 Fr) n=11 sPCNL (22–28 Fr) n=20	Trilogy 1.9mm Trilogy 3.4mm	Prone	370.5 ± 171 mm³/min (6.175±2.85 mm³/sec) 590.7 ± 250mm³/min (9.845±4.167 mm³/sec)	53.4 ± 23.8 minutes (Mean skin puncture exit Time)14.7 ± 12.4 min (mean nephroscopy times) 65.2 ± 23.5/12.0 ± 8.9 minutes	Post op 90.9% One month 90.9% Post op 95% one month 100%	1.24 ± 0.64 g/dL BT - 0 1.23 ± 0.89gm/dL BT -0	1 Fever (Antipyretics) 1 fever Antipyretics 1 fever (Antibiotics)
Thakare, N., et al ,2021	miniPCNL <20 Fr. n=24 sPCNL (≧ 22 Fr) n=133	Trilogy 1.5/1.9mm Trilogy 3.4mm/3.9	(Supine 59.2% Prone PCNL 40.8%)	945.23 (± 1248.9) mm³/min. 65.55 (± 77.7) mm²/ min and (1.09±1.3mm²/sec) (15.75±20.81 mm³/sec)	37 min (mean = 44 min) Median nephoscopy time 7 min (mean = 11 min). median probe active time	83% (fluoroscopy) 90% (visual clearance) Late clearance 81.4% (n=97) X-ray and/or USS, 75% CT scan	1.5 g/dl (mean) BT- 3	fever (n=2), urosepsis (n=3),
Gao, M., et al 2022	sPCNL 24Fr	Trilogy 3.4/3.9mm	Prone	X	88.2 (46.5)	Immediate not given. Late n=95 (91.3) %	3.8g/dl BT - 2 4.5 g/dl BT - 3	Fever (> 38°C) n=10 Sepsis, n= 4 Fever (> 38°C) n=12 Sepsis n=5
Timm, B., et al 2020	miniPCNL 16.5Fr Ho:YAG laser	Trilogy 1.5mm 550micron 30W	Prone	Average; 70.4±35 mm³/min *For (HU<1000) 8.9±1.0 mm²/minutes* For (HU>1000) 3.7±1.6 mm²/minutes Average; 3.4±0.7 mm²/minute *For (HU<1000) 3.6±1.8mm²/ minutes For (HU>1000) 3.1±1.3 mm²/minutes*	90.9±28.1 Lithotripsy duration 80.2±16.7	Immediate Trilogy 55.5% HO: YAG 62.5% 100% of the cases in both Cohorts had stone volume reductions of 95% or more	X X	X X
Large, T., et al 2021	sPCNL Trilogy n=51 24 -30Fr sPCNL ShockPulse-SE	3.9mm /3.1mm 3.77mm/3.3mm	X Surgeon choice X	20.33+/- 27.83mm³/sec	104.4 +/– 48.2 minutes *(induction to end of anesthesia)*	Immediate 56.0% (n=28) At 6-12 weeks	--1.5 – 1.6 g/dl BT 1 -1.6 – 3.3g/dl BT 2	Sepsis (n=1) Sepsis (n=1)

				1.22+/- 1.67cm³/minute 101.3 +/– 92.5 mm²/min 1.67+/- 1.54 mm²/sec 0.77 +/–0.68 cm³/min, p = 0.054) 12.83+/- 11.3mm³/sec	121.1 +/– 59.2 minutes	90.2% (n=46) Immediate 42.9% (n=21) At 6-12 weeks 89.8% (n=44)		
Nottingham, C.U., et al 2020	sPCNL 30F n=49(Renal units) mini-PCNL 17.5F n=1 renal unit	3.9 mm 1.5 mm	X	68.9 mm²/minute. 1.15mm²/sec	X	Immediate 67.6% (25 of 37 Follow-up imaging day 1 or 1-8 weeks. Clearance not given	1 gm/dl	X
Ejaz, M. et al 2023[40]	Size Not mentioned	Not mentioned	Prone	Not mentioned	Group-A 100 (80-130) minutes Group-B 90 (70-120) *p*=0.529 Group-C 75 (65-100)	Group-A, 27(90%) Group B 26(86.7%) Group-C, 18(60%) complete stone clearance (*p*=0.025) late not given	X	Fever A 2(6.7) B 3(10) C 2(6.7) *p*=0.529
Cauni VM, et al 2023	Standard PCNL 24 Fr miniPCNL 15.9 Fr	3.4/3.9 mm probes for standard PCNL and 1.5 mm for miniPerc	Prone	X	Trilogy 43.5 ± 11.24 Master 77.13 ± 19.14 $p < 0.005$	Trilogy 83.4 ± 62.5 vs Lithoclast Master 35.7 ± 15.8 $p < 0.005$ At follow up Trilogy 89.30 Master not given	0.8 g/dl BT 1 x	1 x
Kindler et al 2024	miniPCNL 16.5/17.5Fr	1.9mm Probe	prone - 66%, supine - 34%	X	83min	99% endoscopic & fluroscopic clearance	x	x
Manzo et al 2024	Size Not mentioned	1.5mm probe	Supine	laser -179 mm³/min, trilogy -212 mm³/min	laser - 75.1 min+/- 26.6, Trilogy - 85.9+/- 28.1 min	laser - 70%, trilogy - 88.4%	x	laser - 4(10), trilogy 1(2.3)

Table III: Experiences of the surgical operators from the eleven selected studies based on the Likert scale (a range of 1-10, where 1 represents the worst experience).

Author and Year	Efficacy (Mean)	Ergonomics (Mean)	Other Lithotripters	Comparison to other lithotriptors	Special comment
Patil,A. et al ,2021	X	X	X	X	
Sabnis et al, 2019	X	X	X	X	
Thakare, N., et al ,2021	Ultrasound effectiveness 8.6 Ballistic effectiveness 8.5	8.1 Range 5–10	—	9.0 *(LithoClast*	n=1 excessive noise

	Combination effectiveness 9.1 Suction effectiveness 9.0 Overall effectiveness 9.0			*Master (82%)*	during handpiece activation
Gao, M., et al 2022	X	X	X	X	X
Timm, B., et al 2020	X	X	X	X	X
Large, T., et al 2021				Trilogy 8.7 +/- 0.9 ShockPulse-SE) 8.4 +/-1.8, p = 0.340	Trilogy probe has previously been criticized as being heavy leading to the decreased surgeon satisfaction
Nottingham, C.U., et al 2020	X	6.7	ultrasound (7.3), ballistic (8.1), combination of ultrasound and ballistic (8. and suction (8.4)	3.6 on a 5-point scale, with 3 representing "the same" and 4 representing "slightly better.	the ease of managing settings score of 9.2
Ejaz, M. et al 2023	X	X	X	X	X
Cauni VM, et al 2023	X	x	x	x	x
Kindler et al 2024	50.4	5/5	x	x	x
Manzo et al 2024	x	x	x	x	x

Table IV: A summary of the conclusions described in the eleven selected studies.

Study and Year	Conclusion
Patil, A. et al ,2021	Trilogy™ was more efficient in clearing large renal stones than TFL. However, the stone-free rates and complications were comparable for Trilogy™ and TFL.
Sabnis et al, 2019	Trilogy™ is safe and efficient in clearing larger stone bulk in a shorter time duration. Ease of use, high tissue safety, and optimized suction setup, which avoids fragment blockings are other key features. no conclusions can be drawn and applied to regular practice from this case series
Thakare, N., et al ,2021	The study strongly supports the evidence for the safety, ergonomics, and efficiency of the Swiss LithoClast® Trilogy
Gao, M., et al 2022	EMS Trilogy lithotripsy was effective, safe, and feasible.
Timm, B., et al 2020	The trilogy probe is comparable to the 30W Ho: YAG laser in our series. Improved clearance times for soft stones were found with the Trilogy compared to the 30W Ho: YAG laser.
Large, T., et al 2021	The efficiency, safety, and reliability of Trilogy optimizes stone clearance rates and OR times for large renal stones. both the Trilogy and ShockPulse-SE lithotripters are highly efficient, but Trilogy has significantly less device-related malfunctions
Nottingham, C.U., et al 2020	This multi-institutional study evaluated a new and efficient combination lithotrite that was perceived by surgeons to be highly satisfactory, with an excellent safety and durability profile.
Ejaz, M. et al 2023	Laser and pneumatic lithotripters were more effective in complete stone clearance than trilogy lithotripters
Cauni VM, et al 2023	Swiss LithoClast® Trilogy, a device that combines ultrasonic and ballistic energy is a safe and effective method of lithotripsy for PCNL and miniPerc
Kindler et al 2024	The Trilogy 1.9mm probe is an effective tool to treat even larger stones, with the use of adjunctive irrigation measures to promote visibility and stone extraction.
Manzo et al 2024	The m PCNL with trilogy shows similar results and efficacy to high power laser.

DISCUSSION

The trilogy represents a major uro-technological advance for efficient fragmentation and safe removal of renal stones during PCNL. Any stone treatment technology assessment is based on efficiency and safety in tandem with ergonomics and cost-effectiveness [27]. To our knowledge, this is the first systematic review of its safety, efficiency and ergonomics.

Our review shows that Trilogy is used worldwide. Since its introduction in 2018, data regarding the use of Trilogy in PCNL remains scarce, possibly due to COVID-19 and its effect on elective surgeries [28]. A UK-based study shows significantly prolonged waiting time for elective PCNL in the peri-covid period than pre-COVID 29.

Efficiency Outcome

Lithotripter efficiency is a crucial part of PCNL operation [30,31]. Our review shows that there is variability in stone fragmentation rate using Trilogy from 1.18 ± 0.59 mm^3/sec up to 6.175±2.85mm^3/sec or in terms of Surface area as 0.15 ± 0.017mm^2/sec up to 1.67 ± 1.54 mm^2/sec for mini PCNL. In mini-PCNL a small probe (1.5 to 1.9mm) is used for stone fragmentation and removal. Variability depends on the method of calculating the volume [32] , the reporting method of fragmentation rate, probe size, surgeon experience, stone density, and stone location.

A probe diameter of 3.9mm shows a faster procedural time when compared to the 1.9 mm probe, yet overall stone clearance is the same [16]. When the probe size is decreased from 1.9 to 1.5mm, a decreased clearance rate [24] is seen inferring that Trilogy is more efficient with a probe size of 1.9mm or more. The highest fragmentation and clearance were observed in studies where supine position PCNLs were performed [20].

Impact of Suction on Stone Clearance and PCNL Outcome

A study comparing the Trilogy probe (1.9mm) mini-PCNL with Thulium laser fiber (TFL) showed a significantly better stone fragmentation rate (5.98 ± 4.25mm^3/sec vs. 3.95 ± 1.00 mm^3/sec, $p = 0.015$) and stone clearance (96.6% vs. 76.6% at 48 hours) with both achieving complete stone clearance at 1 month [9]. The use of a Trilogy probe in PCNL, with simultaneous suction of stone fragments, may contribute to higher immediate stone-free rates and clearer vision during the procedure. A prospective study utilizing a Thulium fiber laser with suction in mini-PCNL reported a higher stone fragmentation rate of 5.02 ± 3.93 mm^3/s [8]. A separate study compared the results of a 1.5 mm Trilogy Probe for mini PCNL and noted a stone fragmentation rate of 1.17 ± 0.58mm^3/sec [24].

Stone Density

Trilogy achieves a higher stone fragmentation rate in mini-PCNL for soft stones when compared to Holmium-YAG laser (HU<1000, Trilogy 8.9±1.0 mm^2/minutes vs Homium-YAG laser 3.6±1.8mm^2/minutes) [24].

Stone Volume, Patient Position, and EMS Swiss Lithoclast Trilogy Outcomes

A multicenter study was performed to assess efficiency compared standard PCNL size >22Fr and mini PCNL, size <20Fr where 51.2% underwent supine PCNL [20]. They reported a stone fragmentation rate of 1.09 ± 1.3mm^2/sec and a volumetric 15.75 ± 20.81mm^3/sec. The study also included larger volume stones 7117.63 ± 9581.5 with 18% (n=28) staghorn stones and with 14% (n=23) being partial staghorn stones [20]. This is an important point as a higher stone fragmentation rate is achieved for more complex stones with over half of patients operated on when positioned supine. A meta-analysis comparing the outcome of supine vs prone PCNL has

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found comparable stone clearance for both positions with fewer complications in supine PCNL [33].

Another study showed an intraoperative stone fragmentation rate of (1.22 +/- 1.67 cm^3/minute) using standard PCNL (24-30 Fr tract size) and 3.9 mm Trilogy probe [25]. This is the highest fragmentation rate observed and may be attributed to a higher volume of renal stone (4.18 +/- 4.79 cm^3 or 4180 +/- 4790 mm^3). A separate study assesssed the efficiency of Trilogy with a 3.9mm probe and one case of mini PCNL using 1.9 mm probe [19] and reported a stone fragmentation rate of 68.9 mm^3/minute. Stone fragmentation rate of 590.7 ± 250mm^3/min is reported for Trilogy probes of 3.4 mm [16].

EMS Swiss Lithoclast Trilogy vs Shock pulse SE Lithotripter

A study compared Shock Pulse-SE with Trilogy and found stone fragmentation rates of 1.22 +/– 1.67 and 0.77 +/– 0.68 cm3/min for Trilogy vs ShockPulse-SE ($p < 0.05$). Although the fragmentation rate was higher in Trilogy, the stone-free rate was the same [25]. Another study compared different lithotripters for stone fragmentation in PCNL with *in vitro* and in *vivo* porcine models. The group found good efficacies for all lithotripters in soft stones. The Lithoclast Trilogy was found to be the fastest during all the *in-vitro* fragmentation of stones ($p < 0.001$) and *in-vivo* ($p < 0.008$) trials [34]. A bench study compared different lithotripters that included ShockPulse-SE, LithoClast Select, LithoClast Select and Trilogy with Pneumatic lithotripter for stone clearance. Lithoclast Trilogy was found to be significantly faster ($P < 0.01$) [35].

Safety of Trilogy

Bleeding and EMS Swiss LithoClast Trilogy:

Intraoperative and post-operative bleeding is an important concern when considering PCNL. A separate paper has examined the role of urinary β2-microglobulin excretion during PCNL to assess kidney injury [36]. A study reported a hemoglobin drop 1.24 ± 0.64 gm/dL (mini PCNL) and 1.23 ± 0.89gm/dL (Standard PCNL) with Trilogy [9]. Another study comparing mini PCNL with standard PCNL has shown a Hemoglobin drop of (0.8 ± 0.9 vs. 1.3 ± 0.4 g, $p = 0.01$) [37].

Trilogy vs Lasers safety in PCNL:

In terms of safety, both Trilogy and Lasers have similar success rates and low risk of complications [38]. However, the specific safety comparison between the Swiss Lithoclast Trilogy in PCNL and laser lithotripsy can vary depending on several factors, such as patient's health status, stone size and location, and the surgeon’s experience.

Ergonomics of Trilogy:

Ergonomics in medical procedures refers to the design and use of equipment and instruments to minimize physical strain and discomfort on the operator while maximizing efficiency and patient safety [39].

Ergonomic efficiency has been assessed in 4 out of 11 studies [19,20,25,41]. Using a Likert scale, a multicenter study investigated the operator experience with overall effectiveness of 9.0 compared to previous lithotripters (82% cases of previous lithotriptors were Master LithoClast) [20]. Trilogy compact design requires no assesmbly and is comfortable to use. When compared to dual probe lithotriptor surgeons report a score of 9 out of 10 for a single probe

(Trilogy) [19]. The same study reported an ergonomics score with previous experience of ultrasound (7.3), ballistic (8.1), combination of ultrasound with ballistic (8) and suction (8.4), illustrating that dual device incorporation is an important factor in ergonomics devolpment.

The Trilogy probe 3.9 mm can suction stone fragment size upto 8.6 mm^2 compared to 5.6mm^2 by Swiss lithoclast Master in addition to simultaneous use of combined energy sources. Despite a setting score of 9.2, the same study also reported operator recommendations when compared to other lithotriptors as of 3.6 on a 5-point scale, with 3 representing "the same" and 4 representing "slightly better". The trilogy was perceived as between "the same" and "slightly better" than their current lithotrite [19].

The Trilogy handpiece has a bulkier, heavier frame than other devices and weighs 1200 grams. This requires the surgeon to hold the device for an extended period and may cause hand fatigue, which is difficult when doing a prone PCNL. It also requires the use of a secondary instrument to remove the fragmented stones. On the other hand, laser energy can be delivered using a flexible fiber, reducing the physical strain on the surgeon and improving maneuverability in difficult-to-access areas. This may explain the reason for the ergonomics rating by both studies [19,20]. Further assessment in supine PCNL is required to improve ergonomic efficiency.

In terms of efficiency, the Swiss Lithoclast Trilogy may be faster in breaking larger stones, but the laser-PCNL allows for precise and efficient fragmentation of stones without affecting surrounding tissues.

This review has certain limitations. Studies selected were usually conducted at expert centers, and therefore surgical experience needs to be weighted along with the Trilogy effect. Few studies were retrospective, while prospective studies had conclusions based on very limited data. Except for one study, all studies were nonrandomized. Variability exists where stone volume calculations and fragmentation rate were calculated. Ideally, a randomized multicenter prospective study is required specifically to determine its use in supine PCNL. Scopus was not searched for this review, which is a limitation.

Ergonomics was reported in a few studies with variable assessment questions. All these points highlight the need for a standard definition of these terms within the field, followed by better-designed RCTs and clinical trials to assess the efficacy of the EMS Swiss LithoClast® Trilogy before making any strong recommendations.

CONCLUSION

The conclusion of clinical studies on the EMS Swiss LithoClast Trilogy in PCNL has shown that it is an effective treatment for kidney stones with low complications [9,16,19,20,24]. The Trilogy system is a unique tool that combines three functions pneumatic Lithotripsy, ultrasonic lithotripsy and suction-in-one device. Developing a less heavy handpiece and noise-free mechanism will improve ergonomics and supplement the effectiveness of Trilogy in future.

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